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Optimization of Surface Roughness of AISI P20 on Electrical Discharge Machining Sinking Process using Taguchi Method

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ABSTRACT

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This research aims to obtain optimal value for the surface roughness of the material AISI P20 on the Electrical Discharge Machining (EDM) Sinking process. In the present research, the Taguchi method is used to investigate the significant influence of process variables on the machining performance and determine the combination of process variables on the EDM process. Orthogonal array $L_{18} (2^1 \times 3^3)$ based on the Taguchi method is chosen for the design of experiment. The experiment is replicated twice to finding out the influence of four process variables such as type of electrode, voltage gap, on-time, and off-time on the response performance. Machining performance is evaluated by surface roughness as a response variable that had quality characteristics, smaller is better. These experimental data were analyzed using the Signal-to-noise ratio and Analysis of Variance. The analysis results show that the surface roughness is influenced by the type of electrode and on time. Combination of process variables to obtain optimal surface roughness are using graphite electrodes, and setting values of gap voltage 40 volt, on-time 250 μ s, and off-time 20 μ s. This combination of process variables can be applied to the manufacturing process using EDM sinking in order to produce a good quality product that determined based on the surface roughness value.



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A. INTRODUCTION

One of the classifications of steel made by the American Iron and Steel Institute (AISI), tool steel is divided into several classes based on composition, application, or heat treatment. AISI P20 is a plastic mould steel that is used as a workpiece material for plastic moulding, frame for plastic pressure dies, and hydro-forming tool which is difficult to machine in conventional machining processes under hardening conditions (S. Dewangan & Biswas, 2013). AISI P20 is a tool steel with high tensile strength and good machinability (Kumar et al., 2012). The hardness level of AISI P20 tool steel can increase up to 51 HRC after heat treatment. Surface roughness on plastic moulds using AISI P20 are all concerned because it affects the quality of the product.

Electrical Discharge Machining is a type of non-conventional machinery that has a working system by utilizing some electric sparks through the gap between the electrode and the workpiece filled with the dielectric fluid. The erosion of the material occurs because of the thermal energy generated from the sparks (Banu & Ali, 2016). The thermal energy generated by the plasma channel between the electrode and the workpiece ranges from 8000 °C to 12,000 °C and can reach temperatures up to 20,000 °C. The material will melt and evaporate become debris. The debris will be wasted from the gap by the flow of the dielectric fluid (Srivastava &

Pandey, 2012). EDM can effectively machine on conductive material that have a high level of hardness which is difficult to machine with conventional machining processes and is able to produce products with good surface quality and high precision (Bose & Mahapatra, 2014). EDM Sinking is a type of EDM used in the manufacturing industry to produce moulds. In the EDM Sinking process, the electrons move towards the workpiece in the direction of the z-axis (Jahan, 2019).

In the manufacturing industry, determining the combination of machining parameters is an important factor. The right machining parameters give optimal machining performance results and can improve product quality. Meanwhile, in the EDM process, there are many parameters that significantly influence the results. Therefore understanding the influence of various factors on the EDM process is very important, analysis by statistical methods can be used to select the best combination of process parameters to obtain optimal machining performance.

Taguchi method is a method of optimizing the process of experiment in the field of engineering. The approach using Taguchi method has been applied in several industries and has increased the quality. The fundamental of the Taguchi design method is to identify the parameter settings which improve the quality of the product or process robust to variations of noise factor (Chen et al., 2013). Taguchi method can ensure the quality of the start of the design phase. Advantage of implementing the Taguchi method is it can find influencing factors in a shorter period of time, thereby reducing processing costs (Asiltürk & Akkuş, 2011).

In the EDM sinking process, material eroded occurs on the workpiece. As the frequency of sparks increases, it produces deep craters which increase the surface roughness (Jahan, 2019). Surface roughness plays a very important role in any manufacturing process to identify the quality of the surface produced referring to time and cost. The better quality of surface roughness is seen from the lower surface roughness value. This is the fundamental for conduct research to improve quality, one of which is by applying the design of experiment Taguchi method to optimize the factors in the machining process.

Several experimental studies have been conducted until nowadays to investigate the influence of different parameters on surface roughness for some of materials used in the manufacturing industry. Choudhary et al (2013) investigates EDM process input parameters such as electrode material, current, and pulse on time to surface roughness and material removal rate on 316 stainless steel. The Taguchi method with L_9 orthogonal array and ANOVA was applied to analyze the experimental results. MRR increases with higher current values. The type of electrode is the most influencing factor on MRR, then current and the last is pulse-on time. Meanwhile, the factor that most influences the surface roughness response is the type of electrode, then the current and pulse-on time. For better SR results it can be obtained with lower current values.

Other research was also conducted by Babu & Soni (2016) on the influence of process parameters and optimization of M300 steel on EDM die sinking using the L_9 orthogonal array based Taguchi method. The research results has been found that voltage, current and pulse on time give an important role in the EDM process. Its contribution and the influence of each parameter on surface roughness was determined using Analysis of Variance (ANOVA). The most effective parameter for surface roughness is current followed by voltage and pulse on time. The optimum surface roughness can be achieved with a combination of parameters A1-B1-C2, namely voltage 80 V (level 1), current 0.5 A (level 1), and pulse on time 1.6 μ s (level 2).

Chandramouli & Eswaraiah (2017) focused on using the Taguchi method to optimize the machining process parameters of 17-4 PH steel with copper-tungsten electrodes. The results of this study indicate that the selection of appropriate input parameters such as discharge current, pulse on time, pulse off time, and lift time plays an important role in the Electrical Discharge Machining process. Pulse on time and discharge current parameters show a significant influence on Surface Roughness (SR), while pulse off time parameters have no significant

influence compared to other parameters. ANOVA results showed that pulse on time had the highest percentage contribution to SR is 76.7%. The optimal combination of input parameters and their levels to minimize surface roughness is A1-B3-C1-D1. Confirmation experiments are carried out in order to validate optimal machining parameters. SR decreased from 9.78 μm to 2.89 μm there was an increase of 70.4%. Therefore, significant improvements in Surface Roughness (SR) can be achieved with the Taguchi method approach.

Bahgat et al (2019) conducted research by applying the Taguchi method to produce a high material removal rate (MRR) with low surface roughness (SR) and low electrode wear ratio (EWR) in H13 die steel. The experimental design of L₉ orthogonal array was applied with various parameters such as peak current (I_p), pulse on time (T_{on}), and type of electrode. The electrode material is made of graphite, copper, and brass which are commonly used in EDM machining. Based on the ANOVA results, the peak current (I_p) using copper electrodes is the most influential factor on EWR and MRR. Surface roughness is significantly affected by the pulse on time using brass electrodes. Parameters for maximum MRR use copper with a peak current of 14A and a pulse on time of 150 μs . The optimum parameter for EWR uses copper with peak current 2A and pulse on time 150 μs . Meanwhile, to produce better surface roughness using brass with a peak current of 2A and a pulse on time of 50 μs .

Experiments conducted by Nagaraju et al (2020) with various process parameters of Electrical Discharge Machining (EDM) such as Discharge Current, Voltage, Inter-Electrode gap, Pulse on time to examine the surface roughness response on 17-7 steel. The experimental design used the L₉ orthogonal array. After conducting the experiment, the responses were calculated and the results were analyzed on the Minitab software by applying the Taguchi technique. The optimal combination of parameters to obtain low surface roughness is a current of 8 A, a voltage of 40V, an Inter electrode gap of 150 μm , and a pulse-on time of 600 μs . After performing the Taguchi experiment the surface roughness decreased from 1.85 μm to 1.57 μm . The results of these studies also indicate that the application of the Taguchi method increases the quality of the workpiece surface roughness.

The literature study revealed that each researcher used a different combination of process parameters. They applied design of experiment then analyzed the experimental results statistically to produce optimal machining performance. Besides that, the EDM sinking machining process, the characteristics of each electrode material and workpiece are different. This is because each material has a different composition. Therefore it is necessary to know the suitable material for each machining process with the parameters set to produce the expected output, such as the best surface quality. Present research focuses on determining optimal parameters for the EDM process on AISI P20 in order to produce low roughness values. The experimental design used the Taguchi method and the responses were analyzed using the S/N ratio and ANOVA for evaluating the influence of each parameter on the machining performance.

B. METHODS

1. Taguchi Method

The Taguchi method is one of the methods applied for the purpose of improving product quality, by finding out the factors that influence the quality, then separating them into control factors and uncontrollable factors or noise factor. This method uses an orthogonal array to adjust the factors that affect the process and level. Then the factors and levels will be varied. Only necessary data is collected to determine which factor most influences the results with a minimum number of experiments, thus saving time and resources (Razak et al., 2016). According to R. Choudhary & Singh (2018) the analysis of the taguchi method is expected to achieve the purpose of analyzing influencing variables, analyzing responses in optimal conditions, and minimal experiments being carried out to get the desired results. Taguchi used the ratio of signal-to-noise (S/N) as a selection of quality characteristics. The S / N ratio is a

quality indicator used to evaluate the effect of certain parameters on process performance (Asiltürk & Akkuş, 2011). In this method there are two word, that is the word 'signal' represents the expected (mean) value of the response characteristics and the word 'noise' represents the undesirable value, that is the standard deviation (SD) of the response characteristics. Therefore, the S/N ratio is the ratio of the mean to standard deviation (Chandramouli & Eswaraiah, 2017). Based on the response characteristics, there are three types of S / N ratios, they are nominal-the-best, smaller-the-better and larger-the-better.. Surface roughness response has quality characteristics smaller-the-better according to equation (1). Where n is the number of replications, and y is experimental data (Ikram et al., 2013).

$$\frac{S}{N}ratio = -10 \log \left[\sum_{i=1}^n \frac{y_i^2}{n} \right] \quad (1)$$

Furthermore, ANOVA is used to statistically analyzed the influence of process parameters on the resulting response. ANOVA consists of degree of freedom, sum of square, mean of square, and F-ratio. The F-ratio determines whether the process parameter is significant or not significant at a certain level of confidence. According to Vikas et al (2014) the higher F-ratio value indicates that process parameters have a significant effect on response studied.

2. Experimental Work

The material used as a workpiece in the experiment is AISI P20 with dimensions of 25 mm × 25 mm and a thickness of 20 mm. The electrode material is made from copper and graphite. The machining process is carried out with depth of 0.5 mm. Ariztech ZNC LS 550 EDM sinking machine is used in the experiment as shown in Figure 1. While the measurement of surface roughness was carried out using the Surfest Mitutoyo SJ-310.



Figure 1. Electrical Discharge Machining Sinking

3. Design of Experiment

In this research, the process variables used were the parameters of type of electrode, gap voltage, on time, and off time. Meanwhile, the response variable was surface roughness. This research uses two levels for the type of electrode, three levels for voltage gap, on time, and off time. The determination of the value at each level of the process variable refers to the capabilities and specifications of the EDM machine. In addition, it also considers the parameters

suggested by the machine and looks at data from previous research results. Table 1 shows the value of each process variable include its level.

Table 1. Process Variable Parameters and Level

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
E	Jenis Elektroda		Tembaga	Grafit	-
GV	Gap Voltage	-	30	40	50
TON	On Time	volt	150	180	250
TOF	Off Time	μ s	20	40	60

Determination of the orthogonal array based on the number of parameters, degrees of freedom, and levels. The total degrees of freedom will determine the appropriate orthogonal array (OA) selection to conduct the experiment (Ariffin et al., 2014). The following must be fulfilled: Number of degrees of freedom OA \geq Number of degrees of freedom at the factor level under study, to ensure that the selected OA design will provide adequate degrees of freedom to the experiment being carried out (Kivak et al., 2012). The calculation degrees of freedom of the factor in equation (2) while for orthogonal arrays using equation (3).

$$DF_{fl} = \text{number of level} - 1 \quad (2)$$

$$DF_{OA} = \text{number of experiment} - 1 \quad (3)$$

Table 2. Design of Experiment

Combination	Type of Electrode	Gap Voltage	On Time	Off Time
1.	1	1	1	1
2.	1	1	2	2
3.	1	1	3	3
4.	1	2	1	1
5.	1	2	2	2
6.	1	2	3	3
7.	1	3	1	2
8.	1	3	2	3
9.	1	3	3	1
10.	2	1	1	3
11.	2	1	2	1
12.	2	1	3	2
13.	2	2	1	2
14.	2	2	2	3
15.	2	2	3	1
16.	2	3	1	3
17.	2	3	2	1
18.	2	3	3	2

The orthogonal array suitable to this experiment is $L_{18} (2^1 \times 3^3)$ which is shown in Table 2. The total degree of freedom of the factor is 7, while degrees of freedom for orthogonal array of L_{18} is 17 greater than the degrees of freedom at the factor level. Then the experimental design may be declared eligible.

The orthogonal array has one parameter with two levels and three parameters with three levels. There were a total of 18 combinations with replication twice and randomized were carried out in order to equalize the influence of uncontrollable factors (noise factor) for each treatment. Signal-to-noise (S/N) ratio and the Analysis of Variance (ANOVA) for optimization

process based on the Taguchi method was performed by software Minitab 17. This software is often used in the fields of mathematics, statistics, economics, sports, and techniques to do analysis statistic and quality improvement (Günay & Yücel, 2013).

C. RESULT AND DISCUSSION

1. Data Collection

Measurement of surface roughness using the Mitutoyo SJ-310 Surface roughness tester with a sample length of 0.8 mm. Roughness measurement in horizontal, vertical and diagonal directions (45 ° and -45 ° angles) on the surface of the machined workpiece. Table 3 shows the surface roughness values for each combination of one and two replication experiments. The roughness values for the first and second replications are the average of the four-way measurements. The average value is expressed as surface roughness in units of μm .

2. Data Analysis

The characteristic of surface roughness response quality is smaller the better because the surface roughness result is expected with minimum value. The calculation of S/N ratio smaller the better according to equation 1.

Table 3. Value of Surface Roughness and S/N ratio

Combination	Parameter				Test Result of Surface Roughness		S/N Ratio
	Type of Electrode	Gap Voltage	On Time	Off Time	R1	R2	
1.	Copper	30	150	20	5,035	4,663	-13,7194
2.	Copper	30	180	40	4,727	4,913	-13,6628
3.	Copper	30	250	60	4,539	3,981	-12,6062
4.	Copper	40	150	20	4,656	4,702	-13,4031
5.	Copper	40	180	40	4,160	4,638	-12,8790
6.	Copper	40	250	60	4,561	4,129	-12,7701
7.	Copper	50	150	40	4,426	4,686	-13,1757
8.	Copper	50	180	60	5,094	4,441	-13,5861
9.	Copper	50	250	20	3,761	3,909	-11,6773
10.	Graphite	30	150	60	3,739	4,221	-12,0137
11.	Graphite	30	180	20	4,150	2,338	-10,5473
12.	Graphite	30	250	40	2,175	2,497	-7,3890
13.	Graphite	40	150	40	3,986	3,841	-11,8521
14.	Graphite	40	180	60	3,846	4,053	-11,9335
15.	Graphite	40	250	20	1,834	1,987	-5,6305
16.	Graphite	50	150	60	3,806	4,489	-12,3852
17.	Graphite	50	180	20	4,014	3,237	-11,2370
18.	Graphite	50	250	40	2,665	2,919	-8,9279

The results of the calculation of the S/N ratio can be seen in Table 3. Based on the data in the table, the minimum S/N ratio for surface roughness is in combination 1 that is -13.7194 μm and the maximum. is in combination 15 with the value of -5.6305 μm

Based on the analysis of the S/N ratio calculation, a larger S/N ratio results in accordance with the ideal performance characteristics regardless of the category of performance characteristics. This means that the largest value indicates the best combination to achieve optimal results (Mohanty et al., 2019).

Furthermore, the analysis of variance (ANOVA) was calculated using Minitab 17. Degree of freedom (DF), sum of square (SS), mean of square (MS), F-value, and P-value are shown in Table 4.

Table 4. Analysis Variance

Parameter	DF	Adj SS	Adj MS	F-Value	P-Value
Type of Electrode	1	36,3048	36,3048	33,7448	0.000
Gap Voltage	2	0,5345	0,2672	0,2484	0.785
On Time	2	29,7561	14,8780	13,8289	0.001
Off Time	2	7,7850	3,8925	3.6180	0.066
Error	10	10,7587	1,0759		
Total	17	85,1390			

Based on ANOVA results, hypothesis testing was carried out on each factor to know the significance of factors. Hypothesis testing uses F Test by comparing the F-Value with the F-Table. F-value is defined as the variance ratio caused by each factor and the error. The F-table with the confidence level used is 95% with α 0,05. The testing hypothesis as follows:

H_0 : Factor has no influence on the response

H_1 : Factor influence the response

If the F-value is greater than the F-table, the null hypothesis (H_0) is rejected and it can be concluded that the factor influence the response. Otherwise, if the F-value is smaller than the F-table, the null hypothesis (H_0) is accepted, it can be concluded that the factor has no influence on the response. Based on Table 5, the results of the testing on F-table and F-value, the parameters of the type of electrode and on time have a significant influence on surface roughness. On the other hand, off time and gap voltage do not have a significant influence on surface roughness.

Table 5. Hypothesis testing

Parameter	F-Value	F-Tabel	Decision
Type of electrode	33,7448	4.9646	H_0 is rejected
Gap Voltage	0,2484	4,1028	H_0 is accepted
On Time	13,8289	4,1028	H_0 is rejected
Off Time	3,6180	4,1028	H_0 is accepted

After calculating the S / N ratio and ANOVA, it is continued to determine the factors and levels to produce optimal surface roughness. This calculation refers to Table 3, that is data of S/N ratio. Determination of optimal conditions by looking at the largest mean S/N ratio for each factor level (Cicek et al., 2012). The results of calculating the mean value for each parameter can be seen in Table 5.

Table 5 shows that the maximum mean of the type of electrode parameter at level 2, the voltage gap parameter at level 2, the on-time parameter at level 3, and the off-time parameter at level 1.

Table 6. Optimum Condition Parameter

Level	Type of Electrode	Gap Voltage	On time	Off time
1	-13,0533	-11,6564	-12,7582	-11,0358
2	-10,2129	-11,4114	-12,3076	-11,3144
3	-	-11,8315	-9,8335	-12,5492
Delta	2,8404	0,4201	2,9247	1,5134
Rank	2	4	1	3

Delta is the difference between the largest and the smallest values. While rank based on the delta. Ranking from the largest delta value to the smallest. Rank 1 is the most influential factor namely, the type of electrode, followed by rank 2, that is on time, rank 3 which is off-time and the last is rank 4, namely gap voltage. The following is a graph for the optimum condition parameters which can be seen in Figure 2.

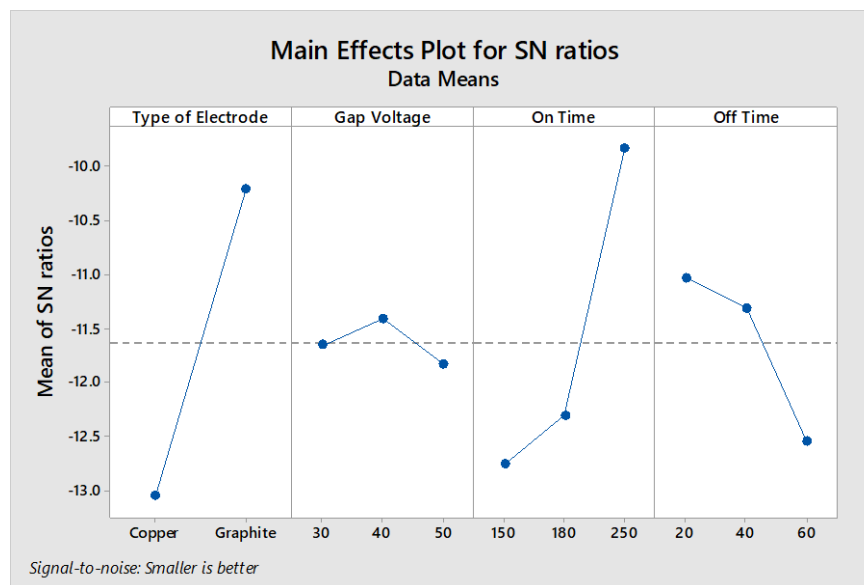
**Figure 2.** Graph of Optimal Factor Level

Figure 2 is the main effect plot for SN Ratios from software Minitab 17. Based on this figure, the predicted parameters for the optimum conditions of surface roughness response using the type of electrode at level 2 is graphite, gap voltage at level 2 with a value of 40 volt, on time at level 3 with a value of 250 μ s and off time at level 1 with a value of 20 μ s.

Surface roughness (SR) is defined as the irregularity of the surface contours of workpiece. The surface contours resulting from the machining process are in the form of craters on a surface formed by the discharge current. Increased surface roughness means that larger and deeper craters are formed on the surface of the workpiece. Otherwise, the forming of a small crater on the surface of the workpiece produces a better surface (Gopalakannan & Senthilvelan, 2012).

The higher value of on time, the longer current flows to the workpiece, and therefore the resulting craters will be wider and deeper (Jahan, 2015). As a result, increases surface roughness. According to the result obtained in this research, a higher value of on time is 250 μ s can produce optimal surface roughness. One of the reason for this could be the transfer of energy hinder by the plasma formed in the gap between the electrode and the workpiece thus forming small craters (S. K. Dewangan, 2014),

The characteristics of each electrode material and workpiece are different. This is because each material has a different composition. Thus, the selection of electrode material is

important in this process (Bahgat et al., 2019). In the present research, the suitable electrode material for producing better surface roughness is graphite.

Off time value is 20 μ s that the smallest value and gap voltage with a value of 40 volt to get surface roughness in optimal condition. There is no spark during the off time because the current flowing through the electrode and the workpiece is cut off (Jahan, 2015). During off time, the dielectric liquid to flush away the debris. The better flushing condition during the EDM process, the less off-time that required for machining, the result is higher efficiency of the entire EDM process (Jahan, 2015).

D. CONCLUSION AND SUGGESTIONS

In this research, design of experiment using Taguchi Method and analyzed carried out by S/N ratio and ANOVA to obtain combination of process parameter on EDM sinking to produce optimal value for the surface roughness of material AISI P20. The conclusions for this research are to get the optimal surface roughness with smaller-the-better quality characteristics using a graphite electrode, and setting parameter gap voltage of 40 volt, on time of 250 μ s, and off time of 20 μ s. With level of confidence 95% ($\alpha = 0.05$), it is known that the parameters of the type of electrode and on time have a significant influence on the surface roughness. while the off time and voltage gap did not significantly influence to the surface roughness. In this research, several process variables were considered constant. For further research, observations can be made of the same response by adding other process variables.

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